DRAINAGE-BASIN CHARACTERISTICS

Robert E. Horton

Factors descriptive of a drainage-basin as related to its hydrology may be classified broadly as:

(1) Morphologic--These factors depend only on the topography of the land forms of which the drainage-basin is composed and on the form and extent of the stream-system or drainage-net within it.

(2) Soil factors--This group includes factors descriptive of the materials forming the groundwork of the drainage-basin, including all those physical properties involved in the moisture-relations of soils.

(3) Geologic-structural factors--These factors relate to the depths and characteristics of the underlying rocks and the nature of the geologic structures in so far as they are related to ground-water conditions or otherwise to the hydrology of the drainage-basin.

(4) Vegetational factors--These are factors which depend wholly or in part on the vegetation, natural or cultivated, growing within the drainage-basin.

(5) Climatic-hydrologic factors--Climatic factors include: Temperature, humidity, rainfall, and evaporation, but as humidity, rainfall, and evaporation may also be considered as hydrologic, the two groups of factors have been combined. Hydrologic factors relate specially to conditions dependent on the operation of the hydrologic cycle, particularly with reference to runoff and ground-water.

One of the central problems of hydrology is the correlation of the hydrologic characteristics of a drainage-basin with its morphology, soils, and vegetation. The problem is obviously complex. In some cases, as, for example, with reference to geologic structure, it is obviously difficult, if not impossible, to express the characteristics of the drainage-basin in simple, numerical terms. Where definite quantitative factors can be devised, as in the case of soils and morphology, several factors must, in general, be used. In the case of soils, for example, much effort has been directed to the derivation of a "one valued" factor fully descriptive of the water relations of a single sample of soil. No single factor which is fully adequate for this purpose is thus far available even for a single soil sample and much less for the complex soil system of a drainage-basin.

The most rational procedure seems to be: (1) To determine numerical factors of the various kinds, wherever possible, which are most general in nature; and (2) to confine attention chiefly to those factors for which a pronounced correlation with runoff-phenomena is found to exist.

In the present paper attention will be confined to a few morphologic factors. The object is to express quantitatively the elements of topography of a drainage-basin which affect the operation of the hydrologic cycle, particularly runoff, thus providing a means for a more definite and specific description of drainage-basins. It is not desirable that qualitative descriptions should be omitted--they are often necessary--but rather that they should be supplemented by specific numerical data.

The basis of all the factors described is the topographic maps of the United States Geological Survey for the United States and equivalent maps where they exist for other countries.

It is evident that quantitative terms used should: (1) Be generally acceptable; (2) capable of determination from data usually available and with a minimum amount of labor; and (3) such that the numerical values determined by different workers for the same area will be nearly identical, or at least of the same order.

Starting apparently with Belgrand in his classical work on the Seine, some quantitative morphologic factors for drainage-basins have been developed in continental Europe and are described by Gravelius in his excellent little book "Flusskunde" and in several papers, by various authors, in Zeitschrift für Gewässerkunde. A few factors, particularly with relation to form and general slope of drainage-basins, have been developed in England and in the United States. In general the factor is designated by the name of its author. Most of the factors given have not hitherto been known or in general use in the United States, excepting as to a few European factors and some developed by the author, which were described briefly a few years ago in the Transactions of the American Society of Civil Engineers (v. 89, 1926, pp. 1081-1086). All the factors hereafter described have been tested by actual use in the author's practice over a period of years.

Form factor

This is the ratio of the width to the length of the drainage-basin. The length to be used is not necessarily the maximum length but is to be measured from a point on the watershed-line opposite the head of the main stream. For a drainage-basin with a side outlet the length may be less than the width. This factor may be expressed in the form

$$F = M/L^2$$

where M is the drainage-area in square miles and L its length. This factor has been considerably used in connection with maximum flood-discharge formulas. In the case of long, narrow drainage-basins such, for example, as basins occupying synclinal valleys and rift valleys, the form factor is indicative of the flood-regimen of the stream. For drainage-basins of irregular form, especially those with permeable soils, form factor is not a sensitive indicator of hydrologic characteristics.

Compactness

This factor, devised by Gravelius, expresses the ratio of the perimeter of the drainage-basin to that of a circle of equal area, or

$$C = \text{Perimeter}/2\sqrt{\pi M}$$

The minimum value is unity for a circular area. The author has not found this factor to be of special value. Numerically it is the same for two areas of identical form, one with the stream-outlet at the side, the other with the stream-outlet at the end, although the hydrologic characteristics of the two basins will, in general, be markedly different.

Mean elevation

Contour-length method--If contours of a given interval are selected and their length measured by opisometer, then the mean elevation of the drainage-basin is

$$E = \Sigma(\ell h)/\Sigma\ell$$

where ℓ is the length and h the elevation of a given contour within the drainage-basin. This method is excellent for small areas and furnishes data which may be used to determine the mean slope of the basin. It is, however, excessively laborious for large areas.

Contour-area method--If the areas between successive pairs of contours of a given contour-interval are measured by planimeter, the mean elevation of the drainage-basin may be expressed by the formula

$$E = \Sigma(a \cdot \frac{h_1 + h_2}{2})/M$$

where a is the area between any pair of contours at elevations h_1 and h_2, respectively. This method is approximate since the mean elevation of the area a is not precisely $(h_1 + h_2)/2$ unless the contour-lengths at elevations h_1 and h_2 are the same. This method is even more laborious than the contour-length method. It, however, furnishes the basis for a hypsometric curve and also for a precise determination of the mean slope of a drainage-basin, as subsequently described.

Hypsometric curve--If the increments of area between successive pairs of contours have been determined by planimeter, a curve can readily be plotted showing the total area within the drainage-basin lying below any given elevation. The mean ordinate of such a curve represents probably the best possible determination of the mean elevation of the drainage-basin. Such a curve is also useful in interpreting the hydrology of drainage-basins where of high relief. From a hyposometric curve the median elevation, such that 50 per cent of the basin is at lower and 50 per cent at higher elevation, can readily be determined. Median elevation is probably a better indicator of various hydrologic conditions, such as mean temperature and duration of snow-cover, than is the mean elevation. Median elevation is usually slightly below the mean elevation but the difference is usually but a few per cent except in case of some basins of abnormal and high relief. The topographic characteristics of different drainage-basins as regards distribution of relief can readily be compared if hyposometric curves are plotted with elevations expressed in terms of percentage of total relief or difference between the highest and lowest elevations within the basin. In determining a hypsometric curve, fairly wide contour-intervals may in general be used, say, for example, 0.1 of the total relief.

Intersection-method--To avoid the excessive labor involved in measuring contour-lengths or areas intermediate between contours for large areas, a drainage-basin may be subdivided into unit squares by suitably spaced lines and the mean elevation taken as the average of the elevations at the intersections of the cross lines.

Mean drainage-basin profile--If a basin is subdivided as in applying the intersection-method and the mean elevations at line intersections of each line crossing the drainage-basin at right-angles to the axis of the stream are plotted in terms of the distance from the mouth of the stream, a profile will be obtained showing the height of land proceeding upstream. The profile of the main stream plotted on the same diagram furnishes a useful basis for comparison of erosion work performed and remaining to be performed in different parts of the drainage-area. The drainage-basin profile also furnishes the best basis for comparison of elevation with hydrologic characteristics of the drainage-basin proceeding from the source toward the mouth of the stream.

General slope

Hydrologically the declivity of the land surface within a drainage-basin has an important but rather complex relation to infiltration, surface-runoff, soil moisture, and ground-water supply to streams. It is one of the major factors controlling the time of overland flow or concentration of rainfall in stream-channels and is of direct importance in relation to flood-magnitude.

Slope may be considered as of two kinds: (a) General slope, and (b) true, or, as here described, "mean" slope. General slope may perhaps best be described as the average slope of a surface generated by a line one end of which is fixed at a given point on the stream above which the slope is to be determined, while the other end sweeps along the watershed-line. General slope does not take into account detailed dissection of the drainage-basin by erosion. Methods in common use for determining general slope are various and in general do not give the general slope as above defined.

The Justin method--This method (Justin, Derivation of runoff from rainfall data, Trans. Amer. Soc. Civ. Eng., v. 77, 1914, pp. 346-384) is based on the assumption that if a drainage basin were square, its average inclination would be the difference in vertical height between its highest and lowest points divided by the side of the square. In applying this method to irregular areas the following formula is used

$$s_g = (H_g - H_L)/5280\sqrt{M}$$

where H_g and H_L are the elevations of the highest and lowest points in the drainage-basin, respectively, and M is the area of the basin in square miles. It is hardly necessary to point out that this method gives arbitrary results which may depart widely from the true slope of the drainage-basin. It is not correct even for surfaces which are true inclined planes, but gives for such planes different values depending on the slope of the surface. For example, for a smooth surface of slope unity, the formula gives the following results in different cases:

Square area................................ $s_g = 1.00$
Rectangle, length = twice the width........ $s_g = 1.42$
Rectangle, length = three times the width.. $s_g = 1.734$

For equal square and circular areas with equal slope, the formula gives 12 per cent greater slope for the circular area.

The Landreth method--The following method, utilized by Olin H. Landreth, applies well to a narrow margin of land surrounding a lake. As applied to a lake, the method consists in determining the average elevation of the watershed-line, subdividing this line into segments, each segment being of about the same elevation and at about the same distance d from the lake throughout its length. The approximate area of each subdivision of the drainage-basin is obtained and the mean slope calculated by the formula

$$s_g = [(H_1 - H_0)/d_1]\ (m_1/M)+[(H_2 - H_0)/d_2]\ (m_2/M) + \ldots$$

where H_0 is the elevation of the lake or large stream used as a datum for each sub-area, and H_1, H_2, etc., are the average elevations of the watershed-line opposite the different sub-areas, m_1, m_2, etc. By this method the slope of each sub-area is given a weight proportional to the fractional part of the total area which it represents.

The Frescoln method--This method (Kipp, Hall, and Frescoln, Drainage of Jefferson County, Kansas, U.S.D.A. Bull. 193, 1915, pp. 12-13) is described by its author as follows: "The value of $\sqrt{s_g}$ is determined for each simple drainage-basin by first dividing the area into units wherever there is a marked change in the surface-relief, as where a flat area joins a rolling or hilly section, each unit wholly on one side of the main stream. The mean $\sqrt{s_g}$ is found for the course which the water will take from each corner of the unit to the outlet of the whole basin and the average of these values is considered the $\sqrt{s_g}$ for that unit. The value of $\sqrt{s_g}$ for the whole drainage-basin is the mean of the values for the separate units, each weighted according to the area of the unit. Special care is required in dividing the drainage-units for a basin consisting of lands rising quickly from a main channel of small slope, that the large slope of the lands near the outlet may not have undue weight in the final value of $\sqrt{s_g}$."

The Frescoln method is in effect an approximate method of determining the average slope from all points within the drainage-basin to the stream-outlet.

For geometrical figures the mean distance of all points on an area from a point on the perimeter of the area can be determined from the surface integral of the area (Byerly, Integral calculus, pp. 201-209).

For a circular area the mean distance from points within the area to a point on the circumference is $4r/\pi = 1.27323r$.

For a square area, the mean distance from points within the square to one corner of the square, whose side is a, is

$$(a/3)\quad \sqrt{2} + \log_e \tan 3\pi/8$$

An approximate equivalent of Frescoln's method consists in dividing the difference between the mean elevation of the area and the outlet of the stream by the mean distance of points within the area from the outlet. Frescoln's method clearly does not give the mean slope of the ground surface but gives more nearly the average slope along assumed lines of drainage of minimum lengths connecting sub-areas with the outlet.

The object of all the factors for general slope has been in general to furnish a basis for determining the time of flood-concentration. In the author's opinion, general slope is not well adapted to that purpose. Time of concentration involves the true mean slope, so far as overland flow is concerned, and the slope of the streams rather than the slope of the ground surface, where channel flow is involved.

Mean slope

The mean slope between a given pair of contours equals the contour-interval divided by the mean distance between contours. The mean distance between a given pair of contours equals the intermediate area divided by the mean length of the contours. For an area as a whole, if the total length of contours has been determined, the mean slope can be expressed by the formula

$$s_g = D\Sigma \ell / M$$

where D is the contour interval, $\Sigma \ell$ is the total length of contours of a given interval, and M is the drainage-area. This formula gives the slope in feet per mile for contour-intervals in feet and contour-lengths and drainage-areas in miles. This method gives good results if the relief is moderate and contours are spaced uniformly. In case of an area a small portion of which has very steep slopes, excessive weight is by this method given to the steep areas and the result cannot be considered as the true average or effective slope of the entire drainage-basin.

With reference to the various methods of determining mean slope it may be noted that some of the earlier topographic maps do not fully reflect erosion-details. In general the greater the length, curvature, or tortuosity of a segment of a contour between two given points, the greater is the slope. Numerical values of slope derived from earlier and less perfect maps are, therefore, likely to be too small, although generally of the right order. A large area may be covered mainly by early maps but if some quadrangles have been resurveyed, a correction-factor can readily be obtained by computing the slope for sample areas from both maps, finding the ratio of the results and multiplying the computed slope for the entire area by this ratio.

<u>Contour-area method</u>--This method seems first to have been suggested by John W. Alvord in 1899. The theory is discussed by Gravelius (Flüsskunde). The mean distance between successive pairs of contours is determined from measurements of contour-lengths and intermediate areas, as in the contour-area method of finding the mean elevation of a drainage-basin. If <u>a</u> is the area between a successive pair of contours separated by an average distance ℓ, then for the basin as a whole

$$s_g = \Sigma(aD)/M\ell$$

The slope of each sub-area is thus given a weight proportional to the fraction of the total area which it represents. One advantage of this method is that it furnishes data from which a slope-profile of the drainage-basin can readily be plotted. The two methods thus far described are, however, both excessively laborious where the drainage-basins are large.

<u>The intersection-line method</u>--In order to reduce the labor of computation of slope of large areas the author has utilized the following method. An area the slope of which is to be determined is subdivided into squares of equal size by lines forming the boundaries between adjacent squares. The number of contours crossed by each subdividing line is counted and the lengths of the lines are scaled. Then the average scale-distance ℓ' between contour-crossings in the subdivision lines is

$$\ell' = \Sigma \ell / N$$

where N is the number of contours crossed and $\Sigma \ell$ is the total length of the subdividing lines. If α is the horizontal angle at which each of two parallel contours crosses an intersection line, then $\ell' \sin \alpha$ is the horizontal distance between the two contours measured normal to the contours. Contours may cross the intersection-lines at all angles from zero to 90°. The mean value of $\sin \alpha$ for angles from 0° to 90° is

$$\int_0^{\pi/2} \sin \alpha \, d\alpha \, / (\pi/2) = 2/\pi = 0.6366$$

If D is the contour-interval or difference in elevation in feet, and L is the average normal horizontal distance between contours, then

$$L = 0.6366 \ell'$$

and the mean slope s_g of the area is

$$s_g = D/0.6366(\Sigma\ell/N) = 1.571\ DN/\Sigma\ell$$

In applying this method it is assumed that each contour crossed represents a difference of elevation along the subdivisional line equal to the contour-interval. Of course it may happen that two adjacent contours are at the same elevation and are separated by land only a little higher or lower. On an average, however, the elevations of summits or depressions between equal contours will differ from that of the adjacent contours by an amount equal to one-half the contour-interval and it can readily be seen that the average declivity between a pair of contours of equal elevation is nearly the same as if the contours were separated by the contour-interval D, so that the method gives nearly correct results even where the subdivision lines cross adjoining contours of equal elevation, as in the case of summits and depressions.

By making the subdivision lines sufficiently frequent, the average slope of an area may be determined with whatever degree of accuracy is desired.

This method has been tested by comparison of slope for the same area computed from the measured total lengths of contours,with, in general, good agreement.

Slope components--The slope-components of a drainage-basin may be obtained in the following manner. A system of equal squares is laid out by parallel lines crossing the drainage-basin in north-south and east-west directions, respectively. The number of contour-crossings within the drainage-basin on the north-south lines is counted. The slope in north or south directions is obtained by dividing the product of the number of contour-crossings and the contour-interval by the total length of the north-south lines. The mean slope in east and west directions can be obtained from contour-intervals on the east-west lines in a similar manner. This method gives the average slope in an east or west direction, for example, regardless of the direction. This is an important factor with reference to infiltration and, in the case of east-west slopes it is important in relation to insolation. In the case of north-south slopes, insolation is more nearly related to the net slope. The net slope may be obtained in a similar manner. For example, with reference to the north-south lines, contour-crossings where the slope is toward the south and those where the slope is toward the north are separately counted and the difference used in obtaining the net slope in a north-south direction.

In the case of the net slope, the same result may be obtained by taking the difference in elevations at the north and south ends of the subdivision lines at their points of intersection with the watershed-line and dividing the total difference by the total length of north-south lines.

The resultant average slope and the orientation of the drainage-basin can be obtained from the slope-components by the following formulae.

Resultant slope--Referring to the figure, in the right triangle cod, if oc is taken equal to unity, then

$$ob = \tan\alpha \qquad (1)$$

$$ob/od = \tan\beta \qquad (2)$$

$$od = \tan\alpha/\tan\beta \qquad (3)$$

If the two slope-components α and β are known, it is required to find the resultant slope-angle oeb = s and its azimuth, $z = 180° - \gamma$, where α is taken as the E-W and β as the N-S slope-component and γ is the angle ocd (strike-angle) of the projection oc of line bc to the trace dc of the intersection of the sloping plane with a horizontal plane.

Since oc = 1, and oe is perpendicular to oc

$$oe = \sin\gamma \qquad (4)$$

$$oe/od = \sin\delta = (\sin\gamma/\tan\alpha)\tan\beta \qquad (5)$$

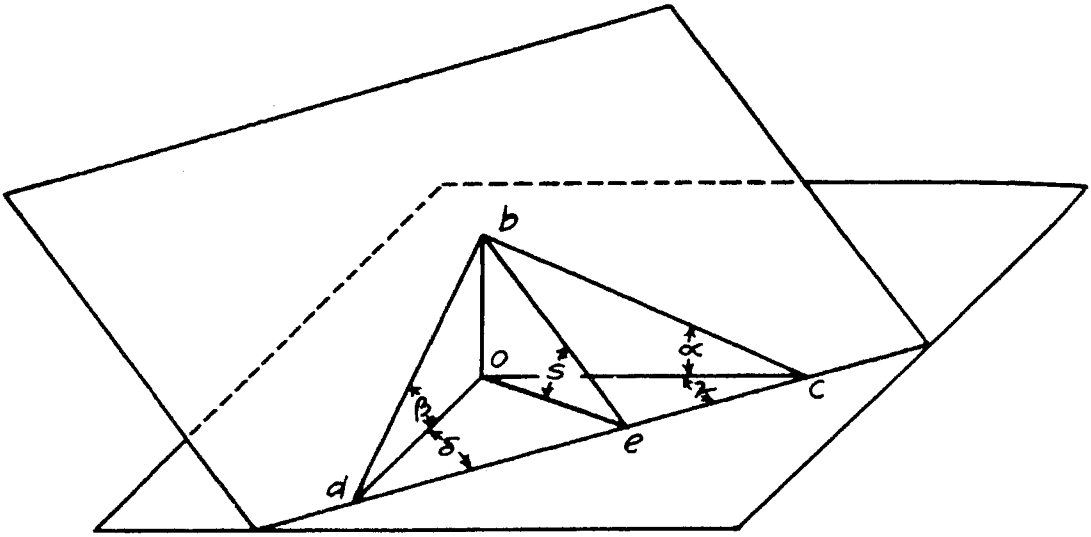

Fig. 1--Relation of resultant slope to slope-components

But $(\delta + \gamma) = 90°$, $\sin \delta = \cos \gamma$, and from (5)

$$\cos \gamma/\sin \gamma = \cot \gamma = \tan \beta/\tan \alpha \tag{6}$$

But $ob/oe = \tan s = \tan \alpha/\sin \gamma$ (from (1) and (4)) (7)

By trigonometry

$$\sin \gamma = 1/\sqrt{1 + \cot^2\gamma} = \tan \alpha/\sqrt{\tan^2\alpha + \tan^2 \beta} \tag{8}$$

and from (7)

$$\tan s = \sqrt{\tan^2\alpha + \tan^2 \beta} \tag{9}$$

and from (6)

$$\cot \gamma = \tan \beta/\tan \alpha \text{ and } z = 180° - \gamma$$

which determines the slope and azimuth of the line of dip of the plane.

Orders of streams

In European practice the main stream is designated as of the first order, larger tributaries of the second order, and so on down, the highest order being the finger-tip tributaries which have no branches. The author prefers the converse procedure, tributaries which have no branches being designated as of the first order, streams which receive only first-order tributaries are of the second order, larger branches which receive only first- and second-order tributaries are designated third-order streams, and so on, the main stream being always of the highest order and the order increasing with the number of successive bifurcations of its tributaries. To determine the order of a stream-system it is always necessary to have available maps showing the ultimate or finger-tip tributaries.

Bifurcation-ratio--It is evident that the number of tributaries of any given order in a drainage-basin increases in a geometrical progression as the order number of the main stream increases. Treated as a geometrical series of ratio r, the sum of the series or the whole number of streams in a basin would be

$$N = (r^{o} - 1)/(r - 1)$$

where o is the order of the main stream. Also if N_1 is the number of tributaries of the first order

$$r = \sqrt[N-1]{N_1}$$

This may be called the bifurcation-ratio. For a number of drainage-basins for which the bifurcation-ratio r has been determined it has been found to be nearly constant for tributaries of different orders, although it varies for different basins. It appears to be an important physiographic characteristic of the drainage-basin. It indicates the complexity and completeness of drainage or the degree of dissection of the drainage-basin, on the one hand, and on the other, it furnishes a simple basis of determining the lengths of streams of different orders and the total length of streams within the drainage-basin. Much further study of this factor is, however, needed before its value as a hydrologic index of a drainage-basin can be fully determined.

Belgrand's ratio--Belgrand utilized the average drainage-area per stream within a given drainage-basin as a hydrologic index for the basin. The number of streams of a drainage-basin equals the number of stream-sources or stream-terminals. If N_s is the number of streams of all classes, Belgrand's ratio equals

$$K_n = M/N_s$$

Drainage-density

Drainage-density defines the length of streams per unit of drainage-area, or

$$D_d = \Sigma \ell / M$$

where $\Sigma \ell$ is the total length of streams within the drainage-basin of order M. This factor seems to have been first suggested by Newmann in 1900 (Zeits. für Gew.). Drainage-density is an excellent indicator of the permeability of the surface of a drainage-basin, its value ranging from 1.5 to 2.0 for steep, impervious areas in regions of high precipitation, down to zero or nearly zero for basins sufficiently permeable so that all the rainfall ordinarily is taken into the soil through infiltration. The reciprocal of the drainage-density is the average distance between streams and one-half the reciprocal of drainage-density is the average horizontal distance between streams and appurtenant watershed-lines, measured at right-angles to the streams. Drainage-density is, therefore, closely related to the length of overland flow.

Stream-density

This is the reciprocal of Belgrand's ratio and is expressed by the formula

$$d_s = N_s/M$$

It is the number of streams per unit of area within the drainage-basin. While similar in form to drainage-density, it does not have the same simple and direct hydrologic significance.

Penck's ratio--Penck suggested the use of the average distance between stream-junctions as a measure of stream-density. It is the ratio obtained by dividing the total length of the stream-channels in the drainage-basin by the number of stream-junctions or bifurcations. Apparently, however, the lengths of the first-order tributaries are not intended to be included and a considerably higher result will be obtained if the first-order tributaries are included than if they are omitted in the calculation. If first-order tributaries are omitted, then Penck's ratio is the average length of the segments into which stream-channels are subdivided by the confluence of tributaries. If J is the number of stream-junctions (that is, the number of streams minus one), then Penck's ratio = $\Sigma \ell / J$.

Interesting graphical methods of deriving and illustrating drainage-density, by means of which the drainage-density in different parts of the area may readily be shown graphically on a map, have been devised by Henkel-Böttcher and by Zuerken (Gravelius, Flusskunde).

Average fall and slope of streams

In compiling morpoholcgic data of a drainage-basin from a topographic map, the length of each stream or tributary should be scaled or measured by opisometer and the result recorded in a proper column in a table, together with the elevation at the source and at the mouth. Data for tributaries of different orders should be separately recorded and summated. From these data the average fall, f_a, and the average slope, S_c, of the streams, can be calculated for all the streams in the drainage-basin or for those of each order separately. The formulas are

$$f_a = \Sigma f/N \text{ and } S_c = \Sigma f/\Sigma \ell$$

where, for a particular stream, f = the elevation at the source minus the elevation at the mouth. The average fall increases with the order of the stream, since no minor tributary can have a total fall equal to that of the main stream. The average slope is, however, greater as a rule for minor tributaries than for those of higher order. The average slope of the tributaries is useful in estimating the effect of stream-channel storage and the length of time required for flood-waves to traverse the stream-channels.

Slope-ratio and tangent-ratio--Slope-ratio is the ratio of the average slope of ground surface to the average slope of stream-channels or, as a formula,

$$r_s = s_g/s_c$$

The value of this ratio is never less than unity, as will appear a little later in connection with overland flow. The tangent-ratio $r_t = \tan s_g/\tan s_c$ is preferable to the simple slope-ratios r_s, as this quantity is used in computing the length of overland flow.

For slopes less than 30° the tangents of angles are so nearly proportional to the angles that they may be approximately expressed by the formula $\tan \theta = 0.188\ \theta$ and for angles less than 30° the slope-ratio may be used in place of the tangent-ratio where the latter is required, without serious error.

Direction and length of overland flow

The distance which water must travel overland before reaching definite stream-channels is of great importance hydrologically, especially in relation to flood-intensities from small areas. It also bears a close relation to the general regimen and hydrology of a drainage-basin since the greater the length of overland flow, the greater, in general, is the infiltration and the less the direct surface-runoff.

Referring to Figure 2-A, consider an idealized stream valley as consisting, between its lateral divides, of two intersecting inclined planes, the trace ob of their intersection being the course of the stream. If oa, Figure 2-A, is a horizontal line on one side slope, then ab is the direction of overland flow. In Figure 2-B, if a'b is the projection of ab on a horizontal plane, then a'b is the length of overland flow, measured horizontally.

Considering a section of the valley in horizontal plan as shown in Figure 2-C, mn is the projection of the divide at one side of the valley, a'b is the horizontal projection of the course of overland flow, bc is the projection of a portion of the stream, and z_c is the horizontal angle between bc and a'b or the horizontal angle at which overland flow from the point a' enters the stream. If w = a'c, the horizontal distance from the divide to the stream, and ℓ_o is the horizontal length of overland flow, then

$$\ell_o = w \operatorname{cosec} z_c \tag{1}$$

The direction of overland flow relative to the stream or the horizontal angle z_c at which overland flow enters the stream can be determined as follows.

Referring to Figure 3, the plane obdg represents a portion of the side slope tributary to the stream at o, the point d being on the watershed-line, the direction of the stream is ao and od is the direction of the resultant slope s_g (dip-slope) of

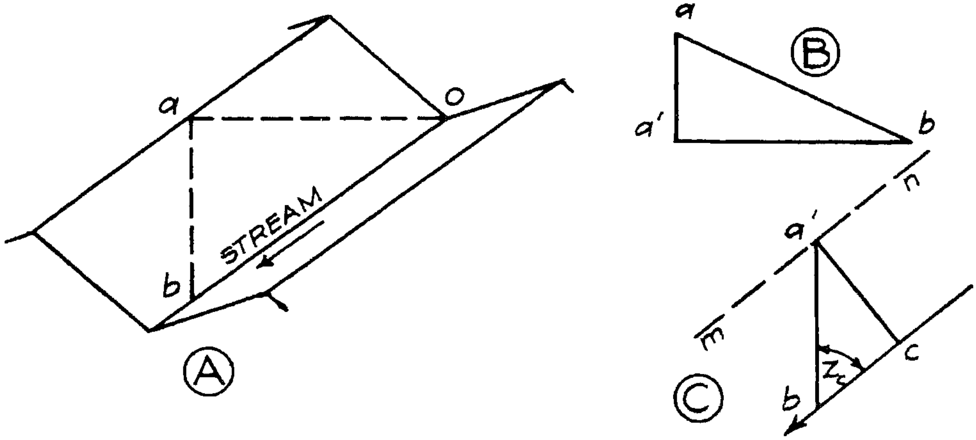

Fig. 2--Length of overland flow

the surface obdg. The stream flows from b to o with the slope s_c. The inclined rectangular plane has a greater slope than that of the stream-channel, otherwise the water would not flow toward the stream but would flow in lines parallel with the stream.

The projection of od on a horizontal plane is oc. The projection of ob on the same plane is oa. Draw be perpendicular to od. The projection of this line is af and since be is at right-angles to the slope it is a horizontal line or line of strike and the lines be and af are parallel. Also ofa, oeb, and oab are right-angles.

In the right-triangles ofa, oef, and oba,

$$ef/of = \tan s_g \qquad of/oa = \cos z_c$$

Also

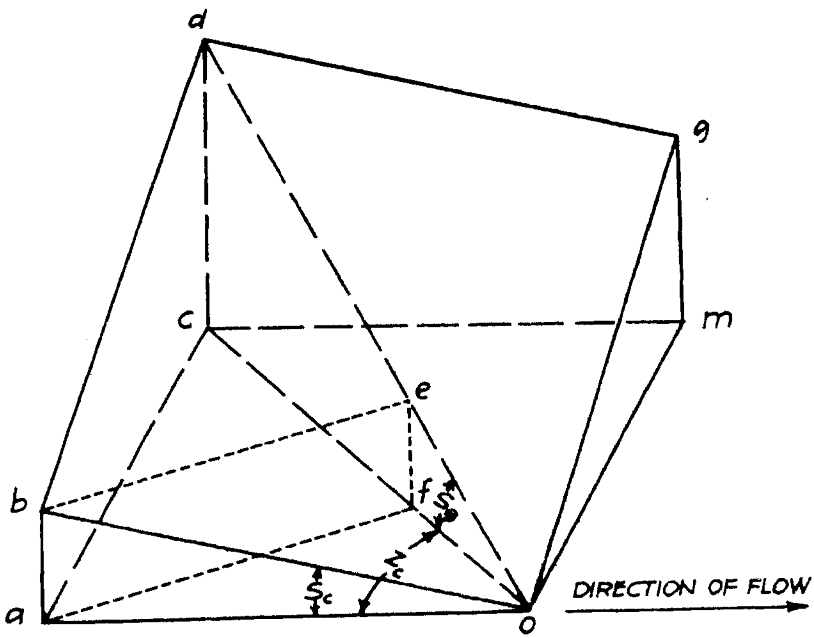

Fig. 3--Direction of overland flow on a plane

$$ab/oa = \tan s_c = ef/oa$$

Therefore

$$\cos z_c = ef \cot s_g / ef \cot s_c = \tan s_c / \tan s_g \qquad (2)$$

But, as before, $\ell_o = w \operatorname{cosec} z_c$ (1). Combining (1) and (2) and simplifying

$$\ell_o = w \tan s_g / \sqrt{\tan^2 s_g - \tan^2 s_c} \qquad (3)$$

For areas not too steep the slope-ratio r_s may be substituted for $\tan s_g/\tan s_c$. Also, $w = 1/2D_d$, where D_d is the drainage density. This gives

$$\ell_o = 1/(2\, D_d \sqrt{1 - r_s^2}) \qquad (4)$$

The average length of overland flow in a drainage-basin can be determined by means of formulas (1) and (2) or by formula (3) or (4) when the resultant ground-surface slope, average slope, average stream-channel slope, and drainage-density are given. The derivation of the formulas is predicated on the assumption that the lateral slopes are planes and that the direction of overland flow is in straight lines.

Contours run normal to the lines of slope. If, therefore, lines normal to the contour are drawn on a surface lying intermediate between two stream-channels, they will represent theoretically the lines of overland flow of the water toward the streams. Contours are deflected upward at a stream-channel and are deflected downstream at the divides between two adjacent streams. There is, therefore, a point of inflection somewhere on each contour between a ridge and a stream. For the usual type of natural drainage-basin, the flow-lines are curved toward the stream as they approach the stream-channel.

The exact determination of the average distance which rain must travel overground to reach the stream-channels is impracticable. The water does not always flow parallel with the direction of the slope but, especially on tilled areas, is likely to follow minor depressions or tillage furrows in the ground surface, which on hilly sides are usually at right-angles to the direction of slope. It follows that the total length of overland flow is usually greater than the computed length.

The author believes that the formulas give results of the right order and furnish a basis of correlating differences in hydrologic regimen of different streams with their most important topographic characteristics--slope and drainage-density.

Referring again to formula (1) it will readily be seen that the smaller the tangent-ratio or the greater the lateral slope relative to the stream-slope, the larger will be the angle z_c. In other words, for steep valley slopes, overland flow tends to enter the stream at right-angles, while for flat areas the angle of inflow of surface-runoff becomes more acute as the channel-slope approaches equality with the ground-slope.

The development of tributaries on lateral slopes of a main stream-valley follows closely the lines of overland flow. Maps of drainage-patterns show in general that parallel tributaries entering the main stream nearly at right-angles are characteristic of steep, serrated hillside slopes, and that tributaries enter larger streams at more and more acute angles as the surface relief decreases.

Application of data--Space does not permit presentation of morphologic factors which have been worked out for many drainage-basins in eastern United States. The following tabulation, from data computed by Glenna B. Holmes (Report on regulation of floods of Onondaga Creek, New York, to the Intercepting Sewer Board of the City of Syracuse, New York), serves to illustrate the nature of the results, the manner in which given factors vary for different streams, and the degree of correlation between the morphologic factors, particularly slope and drainage-density, and maximum flood-discharge.

Physiographic factors for several streams in New York State

Items	Onondaga Creek, Syracuse	West Canada Creek, Hinckley	Little Tonawanda Creek, Linden	Rondout Creek, Lackawack	Six Mile Creek, Ithaca
Elevation, from - to...	370-1800	1160-3500	1060-1700	630-2900	420-1800
Area of basin, sq. mi..	108.0	374.0	22.5	102.2	84.4
Drainage-density.......	1.14	1.65	1.13	1.03	2.20
Slope of streams, ft/mi	132.5	73.3	114.7	201.7	151.7
Slope of land, ft/mi...	445.	522.	381.	935.	562.
Slope-ratio, r_s........	0.297	0.140	0.301	0.216	0.270
Horizontal angle.......	72° 40'	82° 00'	72° 30'	77° 30'	74° 20'
Average distance between streams, mile...	0.877	0.606	0.885	0.970	0.454
Distance, divide to streams, mile.........	0.438	0.303	0.442	0.485	0.227
Average distance overland flow, mile.......	0.460	0.306	0.464	0.497	0.236
Flood c.f.s............	6000.	39000.	2500.	14000.	8980.
Date...................	Mar.13,1920	Apr.21,1869	May 10,1910	Nov.9,1913	June 21,1905
Sec.-ft. per sq. mi....	55.5	104.6	113.5	140.	195.2
Reference..............	S.I.S.B.	E.R.,1913, p.402	W.S.P.No. 544,p.74	N.Y.S.E., 1924,p.305	W.S.P.No. 162,p.4

References in table: S.I.S.B. = Syracuse Intercepting Sewer Board; E.R. = Engineering Record; W.S.P. = Water-Supply Paper, U.S. Geological Survey; and N.Y.S.E. = New York State Engineer.

Voorheesville, New York

THE 1929 FLOODS ON EASTERN NORTH CAROLINA STREAMS

Thorndike Saville

North Carolina has a land area of 48,740 square miles. Of this about seven-eighths is situated east of the Blue Ridge Mountains. The streams draining this large area fall into two groups: (1) Those rising in the Blue Ridge Mountains and thence flowing in a southeasterly direction through the Piedmont Plateau into South Carolina; and (2) those rising in the Piedmont region and flowing southeasterly across the Piedmont and Coastal Plain regions, finally discharging into the Atlantic Ocean or into the North Carolina sounds bordering that Ocean. The three principal streams of this latter class are the Cape Fear River (D.A. = 8,500 square miles), the Neuse River (D.A. = 4,450 square miles), and the Tar River (D.A. = 3,075 square miles). This study is concerned principally with a description of certain hydrological characteristics of the floods occurring on the Cape Fear and Neuse rivers in September and October 1929.

The Cape Fear and Neuse rivers occupy adjacent drainage-basins, and have their origin in the Piedmont Plateau in North Carolina (see Fig. 2) a few miles south of the Virginia border. Both flow in a general southeast direction and have their entire drainage-basins in North Carolina. The Cape Fear crosses the "fall line" into the Coastal Plain a short distance above Fayetteville. The Neuse crosses the "fall line" near Smithfield.

No reliable records of stream-flow on these rivers exist prior to 1922. The United States Weather Bureau has maintained a number of river-stage reporting-stations on the lower portion of these rivers for a considerable period, but only at the Fayetteville station has it been possible to rate the section and make estimates of flow prior to 1922.

Since 1922 the North Carolina Department of Conservation and Development has been active in stimulating the establishment of standard gaging-stations on these two rivers and their principal tributaries. The Army Engineers also established a number of stations on the rivers in 1927 and 1928, which are now being financed from other sources.